

EE 267: Introduction and Overview



Gordon Wetzstein
Stanford University

EE 267 Virtual Reality

Lecture 1

stanford.edu/class/ee267/

virt·u·al re·al·i·ty
vərCH(əw)əl rē'älədē

the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.



simulation & training



visualization & entertainment



remote control of vehicles, e.g. drones



gaming



robotic surgery



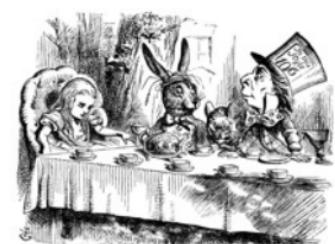
architecture walkthroughs



education



virtual travel



a trip down the rabbit hole

VR at Stanford's Medical School



- Lucile Packard Children's Hospital: used to alleviate pain, anxiety for pediatric patients
- VR Technology Clinic: applications in psychotherapy, mental health, for people with phantom pain, ...
- help train residents, assist surgeons planning operations, ...

photo from Stanford Medicine News

National Academy of Engineering

“Enhance Virtual Reality” is 1 of 14 NAE grand challenges for engineering in the 21st century



image from NAE

Exciting Engineering Aspects of VR/AR

- cloud computing
- shared experiences



- CPU, GPU
- IPU, DPU?



- compression, streaming



- VR cameras

- photonics / waveguides
- human perception
- displays: visual, auditory, vestibular, haptic, ...

- HCI
- applications

Where We Want It To Be



Personal Computer
e.g. Commodore PET 1983



Laptop
e.g. Apple MacBook



Smartphone
e.g. Google Pixel



A Brief History of Virtual Reality

Stereoscopes

Wheatstone, Brewster, ...



VR & AR

Ivan Sutherland



Nintendo Virtual Boy



VR explosion

Oculus, Sony, HTC, MS, ...



1838

1968

1995

2012-2022

???

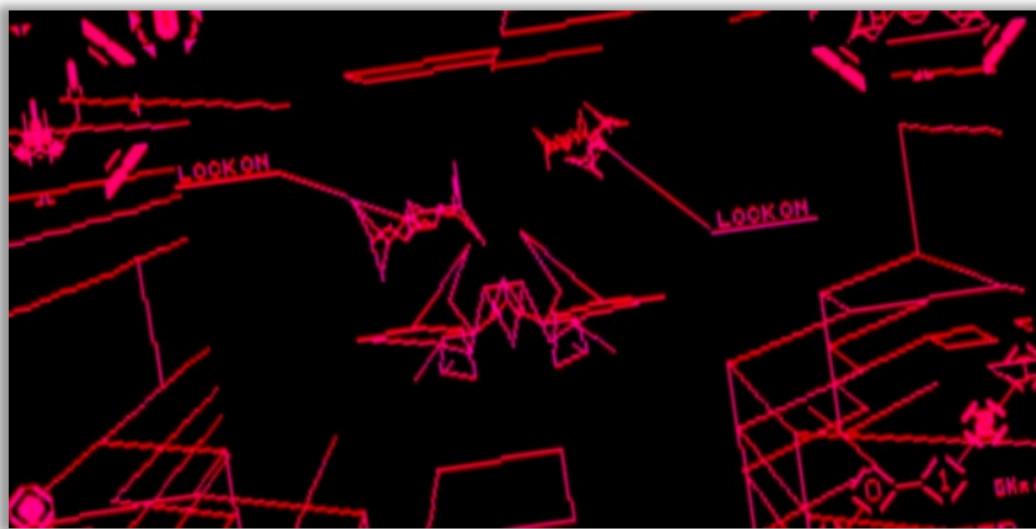
Ivan Sutherland's HMD

- optical see-through AR, including:
 - displays (2x 1" CRTs)
 - rendering
 - head tracking
 - interaction
 - model generation
- computer graphics
- human-computer interaction



Nintendo Virtual Boy

- computer graphics & GPUs were not ready yet!

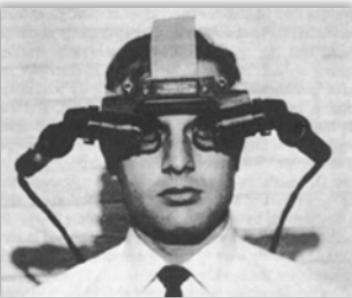


Game: Red Alarm

Where we are now







electronic /
digital

1968



HCI /
haptics

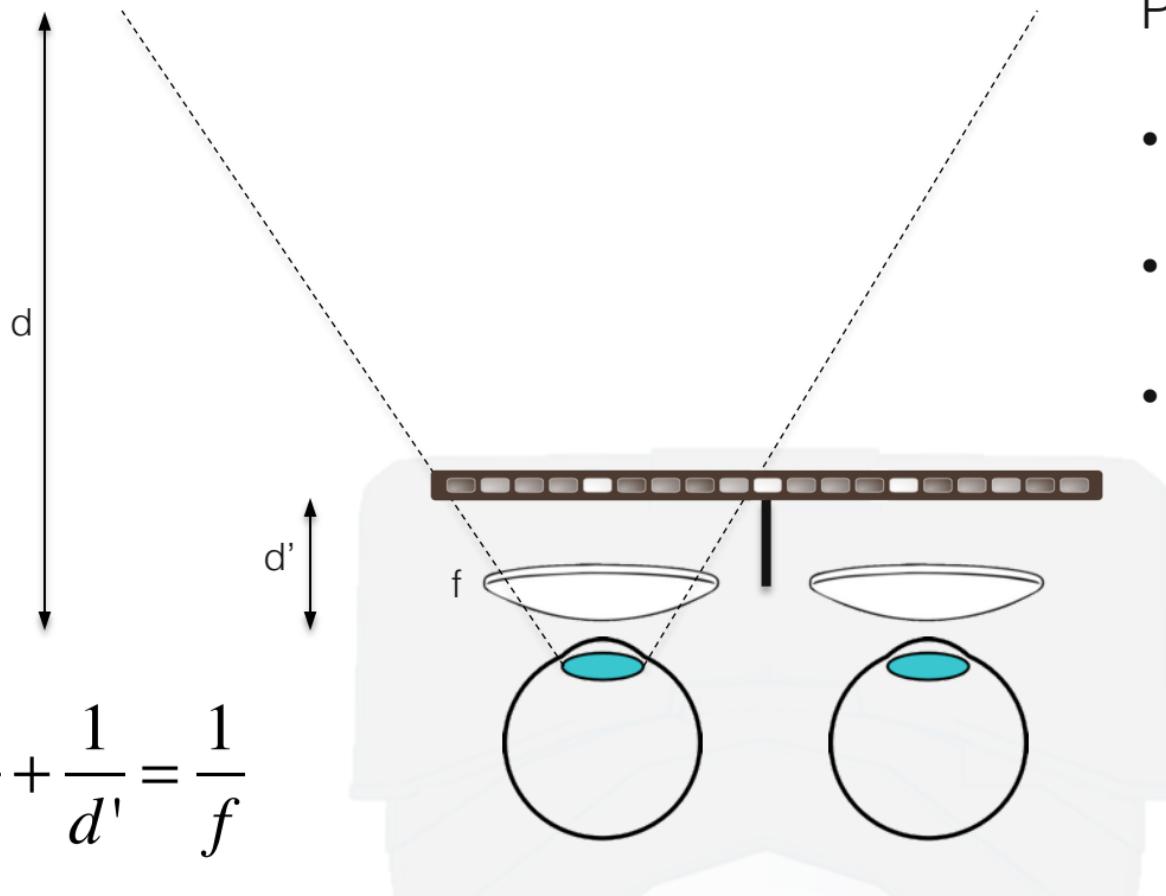
1980s



low cost,
high-res,
low-latency!

2000s

Virtual Image



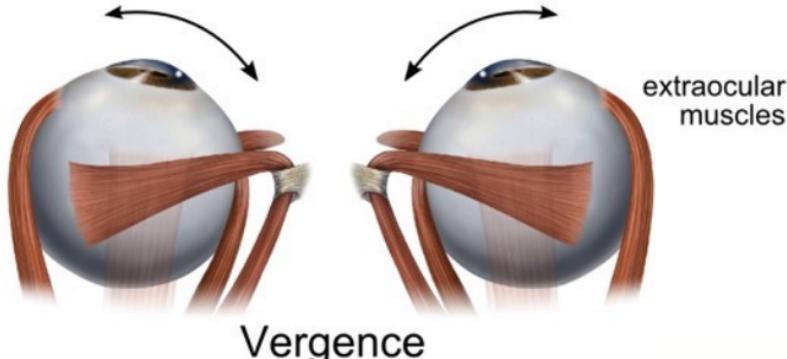
$$\frac{1}{d} + \frac{1}{d'} = \frac{1}{f}$$

Problems:

- fixed focal plane
- no focus cues 😞
- cannot drive accommodation with rendering!

Oculomotor Cue

Stereopsis (Binocular)

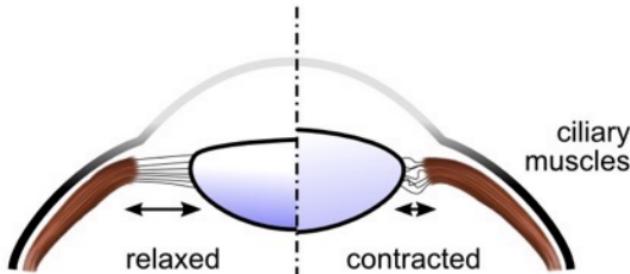


Vergence



Binocular Disparity

Focus Cues (Monocular)



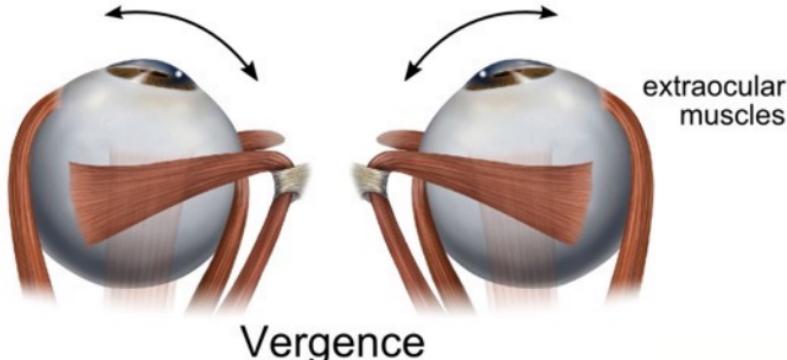
Accommodation



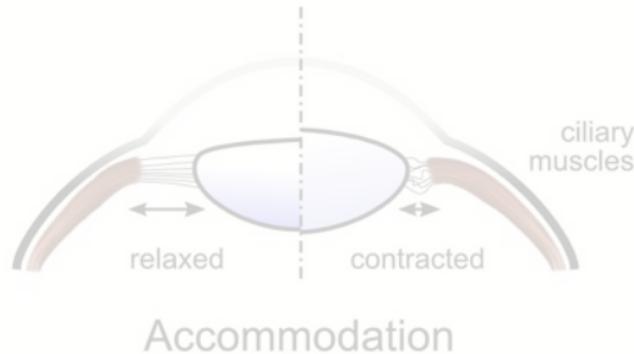
Retinal Blur

Oculomotor Cue

Stereopsis (Binocular)



Focus Cues (Monocular)



Visual Cue



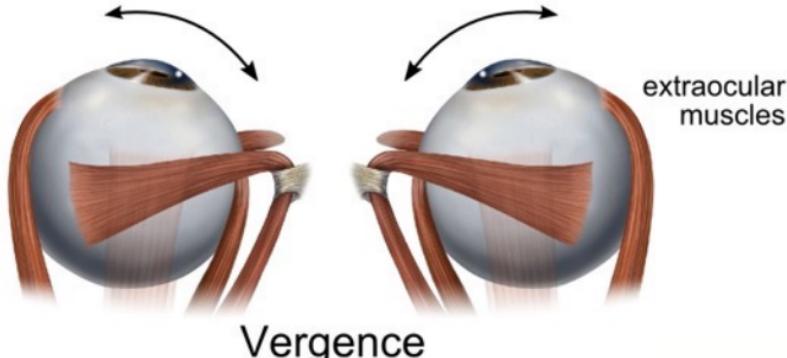
Binocular Disparity



Retinal Blur

Oculomotor Cue

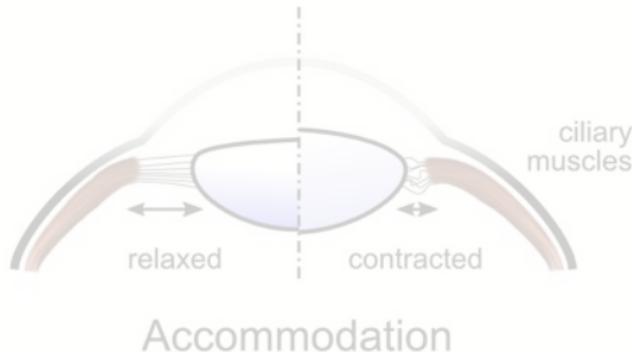
Stereopsis (Binocular)



Binocular Disparity

Visual Cue

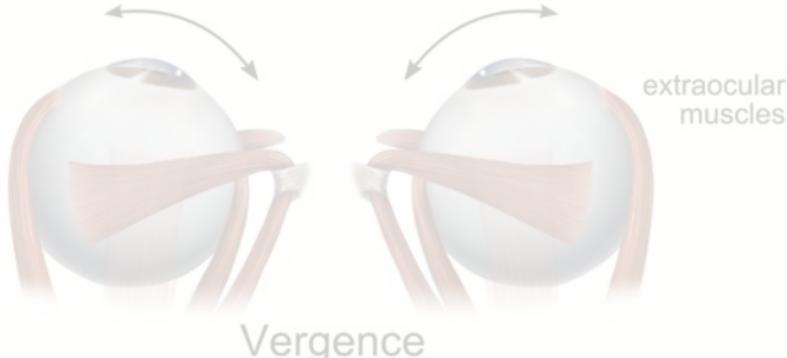
Focus Cues (Monocular)



Retinal Blur

Oculomotor Cue

Stereopsis (Binocular)

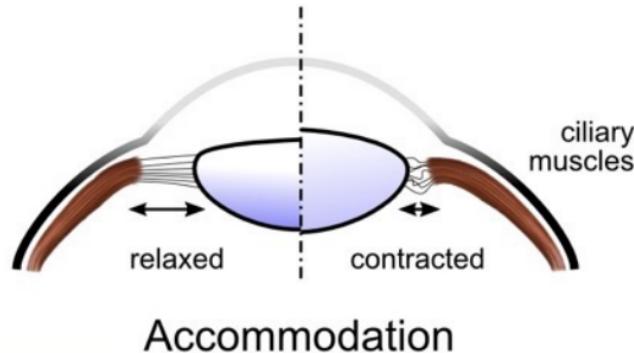


Visual Cue

Binocular Disparity



Focus Cues (Monocular)

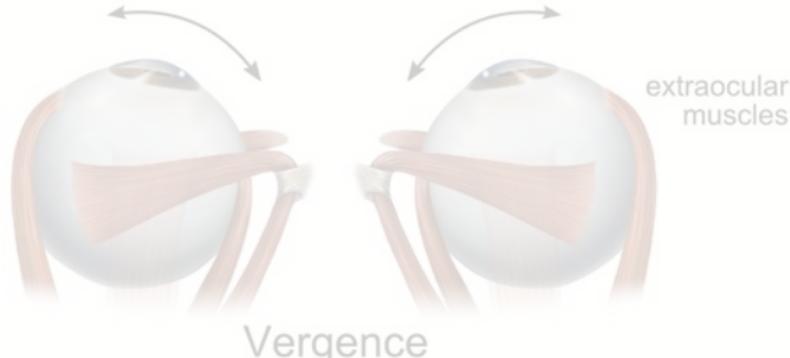


Retinal Blur



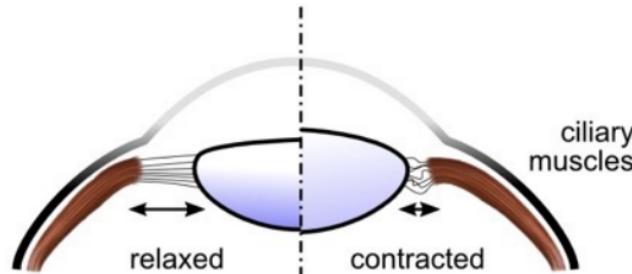
Oculomotor Cue

Stereopsis (Binocular)



Binocular Disparity

Focus Cues (Monocular)



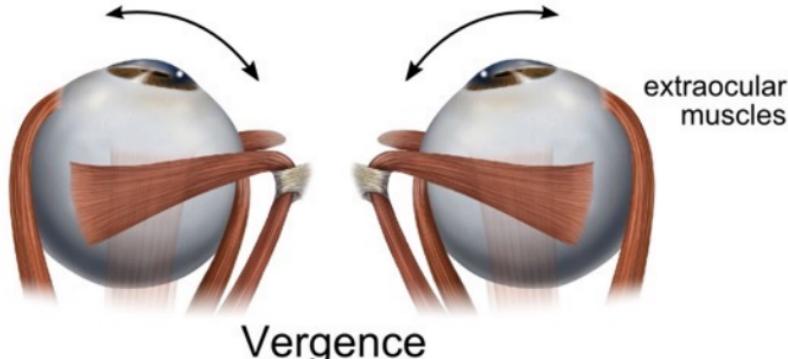
Accommodation



Retinal Blur

Oculomotor Cue

Stereopsis (Binocular)

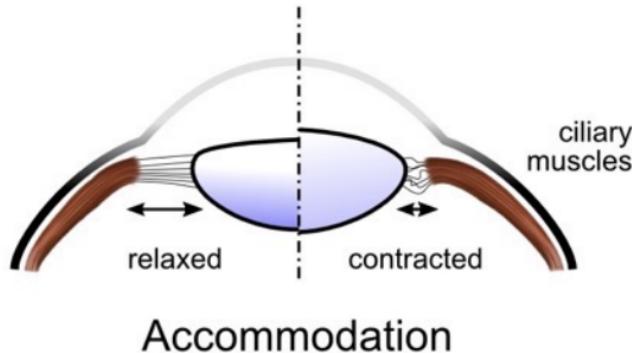


Vergence



Binocular Disparity

Focus Cues (Monocular)



Accommodation



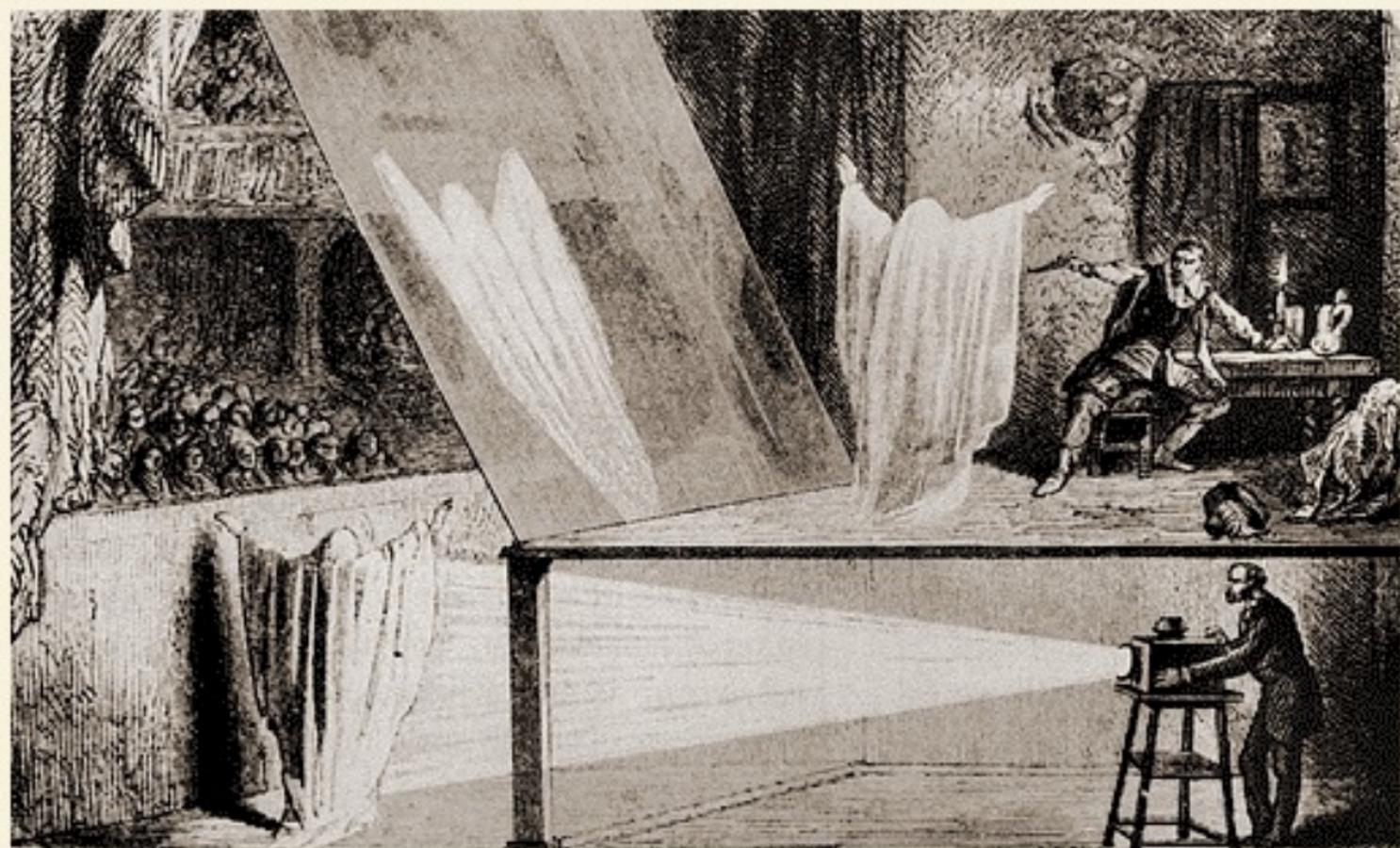
Retinal Blur

Visual Cue

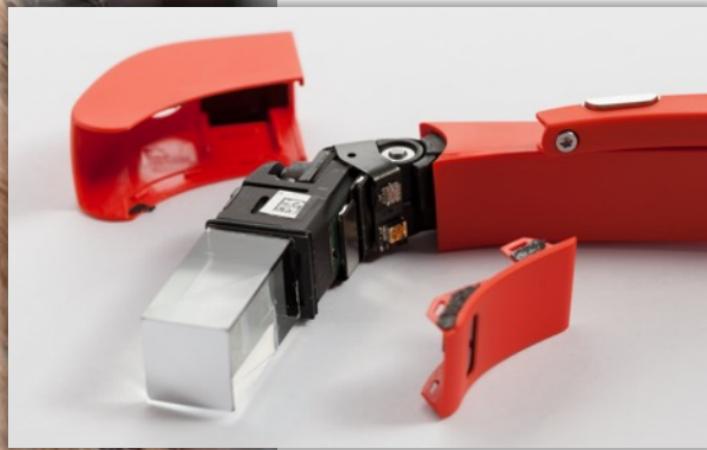
Augmented Reality

(not really covered in this class, but closely related)

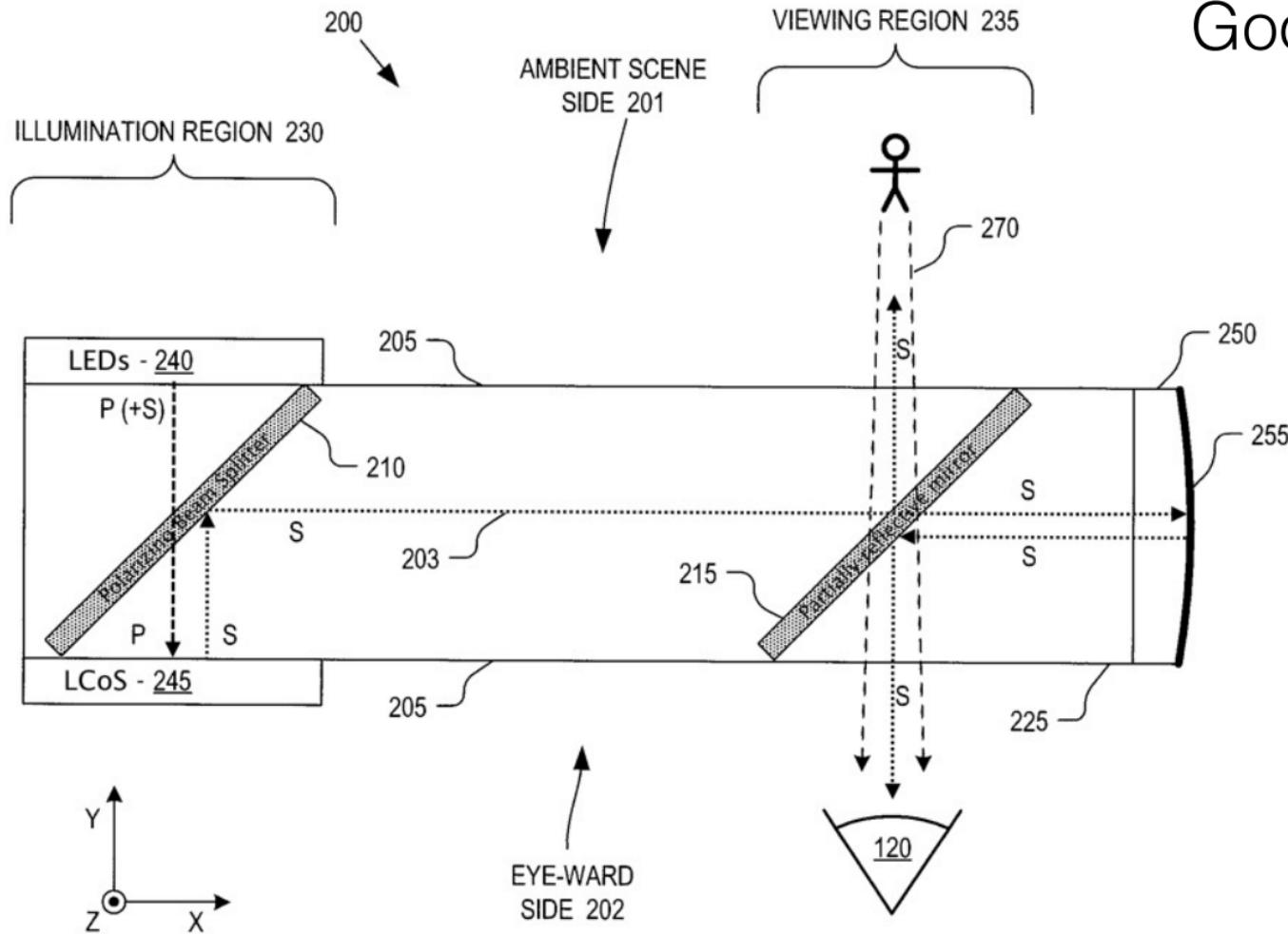
Pepper's Ghost 1862



Google Glass



Google Glass

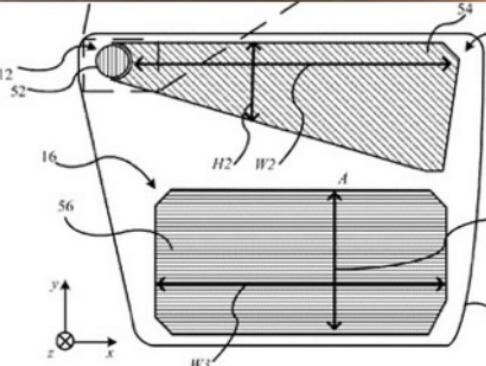
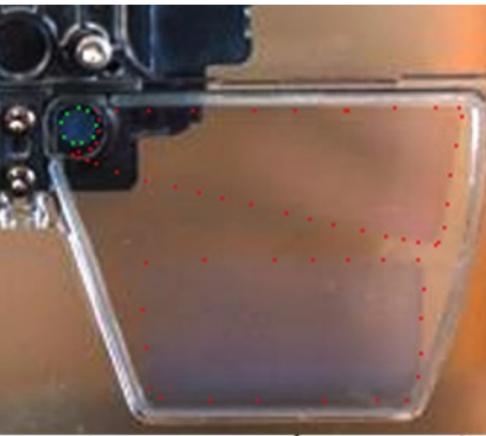


Microsoft HoloLens



Microsoft HoloLens

- diffraction grating
- small FOV (30x17), but very good image quality



US 2016/0231568

Fig. 3B

(16) United States

(21) Patent Application Publication

(30) Pub. No.: US 2016/0231568 A1

(41) Pub. Date: Aug. 11, 2016

(54) WAVEGUIDE

(71) Applicant:

Microsoft Technology Licensing, LLC,
Redmond, WA (US)

(72) Inventor:

Paul Saarikko; Tapio (T1); Paul
Kostamo; Tapio (T2)

(21) Appl. No.:

14/861,697

(22) Filed:

Feb. 9, 2015

(51) Int. Cl.:

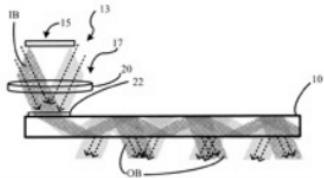
G02B 27/0072 (2013.01); G02B 6/0085
(2013.01); G02B 15/02 (2013.01); G02B 27/0078
(2013.01); G02B 15/04 (2013.01); G02B 27/0079
(2013.01)

(52) U.S. Cl.:

CPC — G02B 27/0072 (2013.01); G02B 6/0085
(2013.01); G02B 15/02 (2013.01); G02B 27/0078
(2013.01); G02B 15/04 (2013.01); G02B 27/0079
(2013.01)

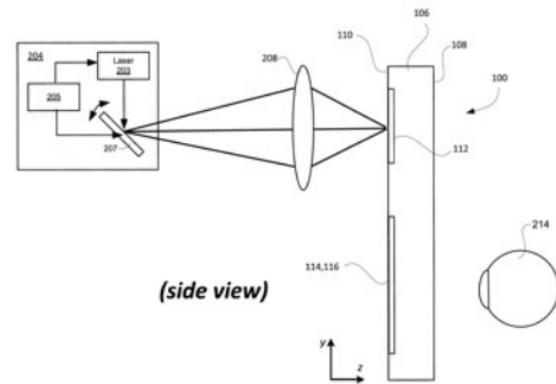
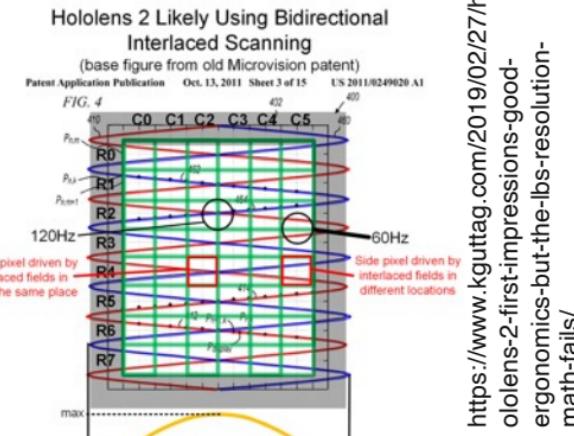
(57) ABSTRACT

A waveguide has a front surface and a rear surface. The waveguide is a display system and arranged to guide light from a light engine onto an eye of a user to make an image visible to the user. The waveguide includes a lens at least partially positioned at the front and rear surfaces. A first portion of the front or rear surface has a structure which causes light to change phase upon reflection from the front or rear surface by a first amount. A second portion of the same surface has a different structure which causes light to change phase upon reflection from the second portion by a second amount different from the first amount. The first portion is offset from the second portion by a distance which substantially matches the difference between the second amount and the first amount.



Microsoft HoloLens 2

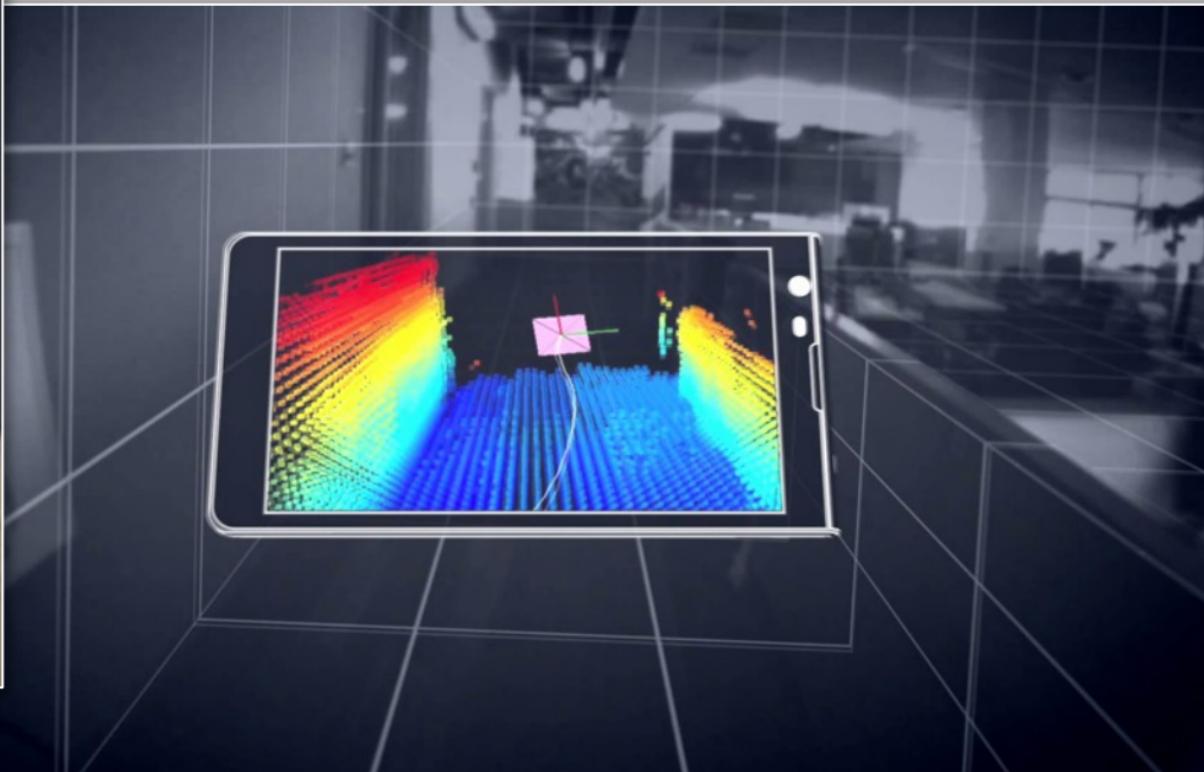
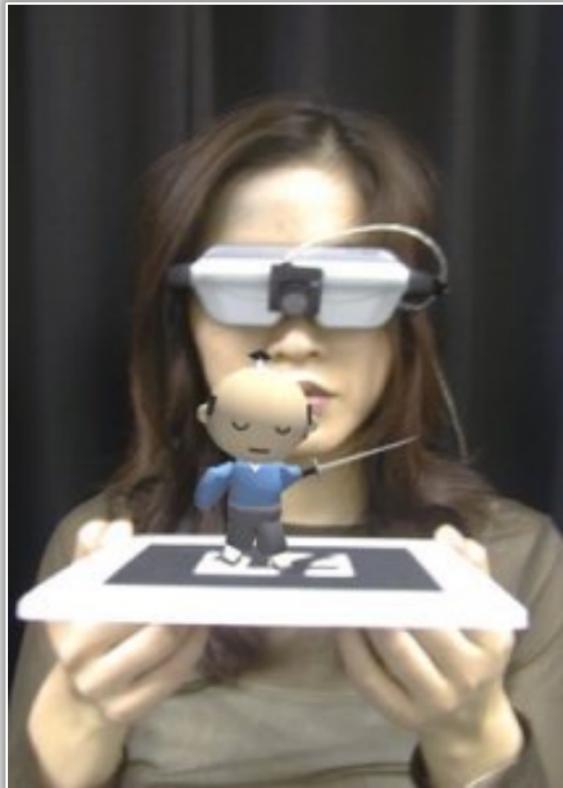
- laser-scanned waveguide display
- claimed 2K resolution per eye (2560x1440), probably via “interlaced” scanning
- field of view: 52° diagonally (3:2 aspect, 47 pixels per visual degree)



Wall et al. US 10,025,093 2018

<https://www.kguttag.com/2019/02/27/hololens-2-first-impressions-good-ergonomics-but-the-lbs-resolution-math-fails/>

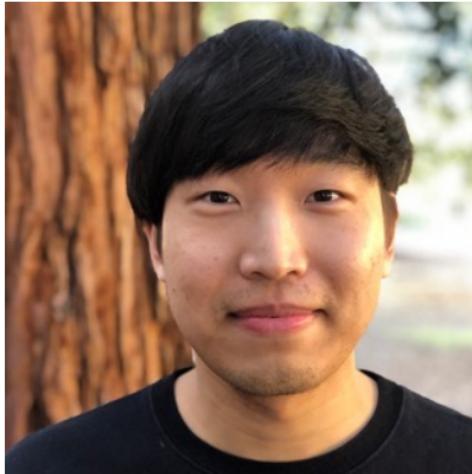
Video-based AR: ARCore, ARKit, ARToolKit, ...



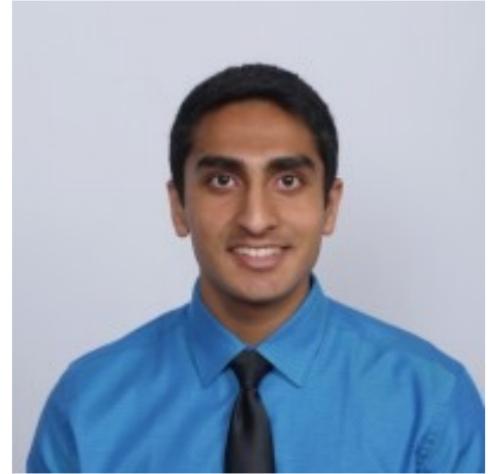
EE267 Instructors



Gordon Wetzstein



Suyeon Choi



Manu Gopakumar

Associate Professor of EE/CS

Research Assistants and EE267 – VR experts!

About EE 267

- experimental class, only taught at Stanford and also only a few times so far (help us improve it!)
- COVID-19 situation is particularly challenging for us – please be patient
- lectures + assignments = one big project – build your own VR HMD
- all hardware provided (shipped), but must return at the end
- enrollment limited, because it's a lab-based class and we only have limited hardware kits
- 1 or a few guest lectures by leaders toward the end of the quarter

About EE 267 - Goals

- *again, primary goal: build your own HMD!*
- learn what is necessary to get there along the way:
 - computer graphics / real-time rendering
 - human visual system
 - magnifying optics
 - orientation (i.e. “3 DoF”) and pose (i.e. “6 DoF”) tracking
- very technical course! lots of math and programming!!

About EE 267 – Learning Goals

- understand fundamental concepts of VR and Computer Graphics
- implement software + hardware of a head mounted display
- learn basic WebGL/JavaScript and Arduino programming

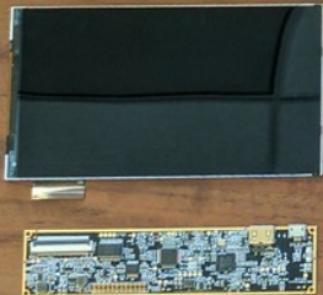
What EE 267 is not!

- *not a* “build VR application in Unity” course, although you can do that in your project
- *not a* “here is a high-level overview of VR” course – you need to implement everything discussed in the lectures in your weekly assignments
- *not a* super hard course, but requires consistent work effort and time commitment throughout the quarter

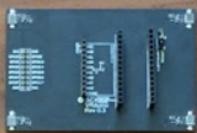
HMD
Housing &
Lenses



6" or 5.5" LCD
& HDMI Driver
Board



VRduino



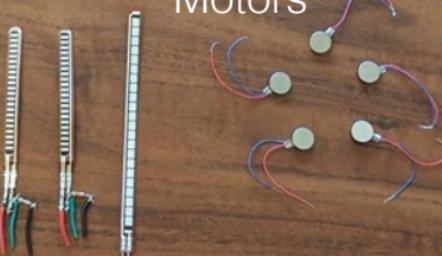
IMU &
Teensy



HDMI Cable



Vibration
Motors



Flex Sensors



2x USB Cable

HMD Housing and Lenses



- View-Master VR Starter Kit (\$15-20) or Deluxe VR Viewer (\$23)
 - implements Google Cardboard 1.0/2.0
 - very durable – protect flimsy LCDs

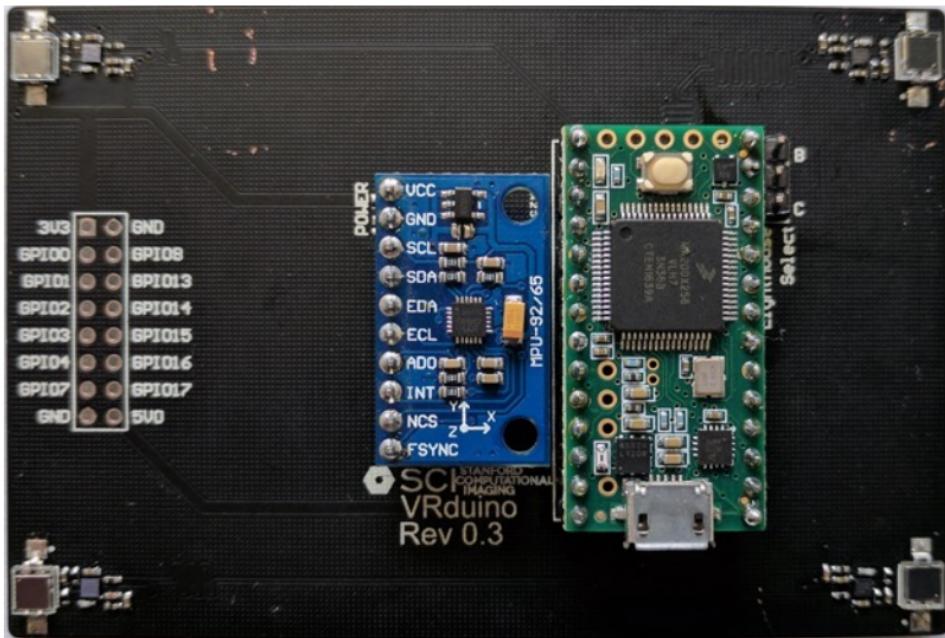


Display

- Small LCDs, either 6" or 5.5"
- HDMI driver boards included
- super easy to use as external monitor on desktop or laptop

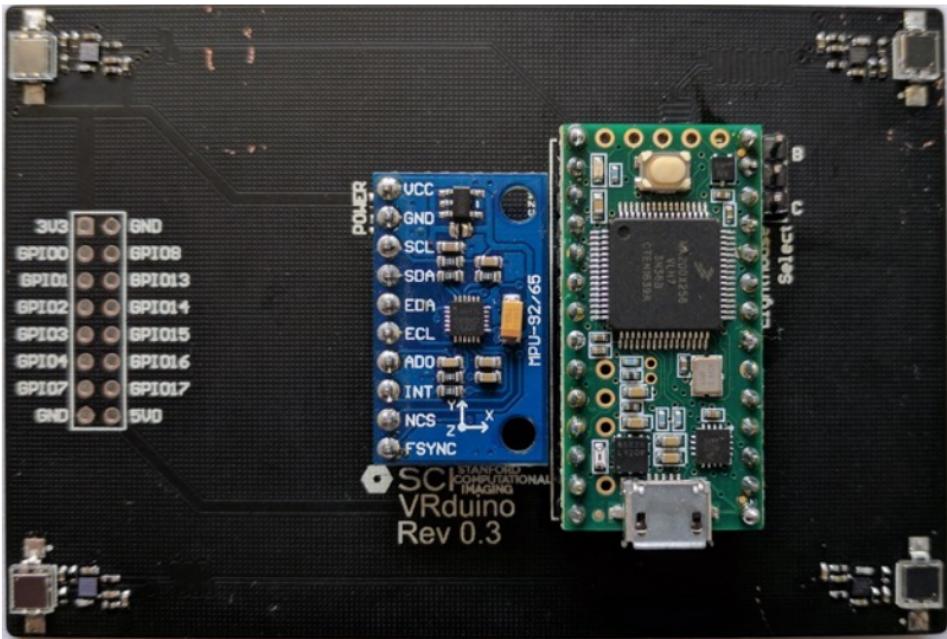


VRduino



- Arduino-based open source platform for:
 - orientation tracking
 - positional tracking
 - interfacing with other IO devices
- custom-design for EE 267 by Keenan Molner
- all HW-related files on course website

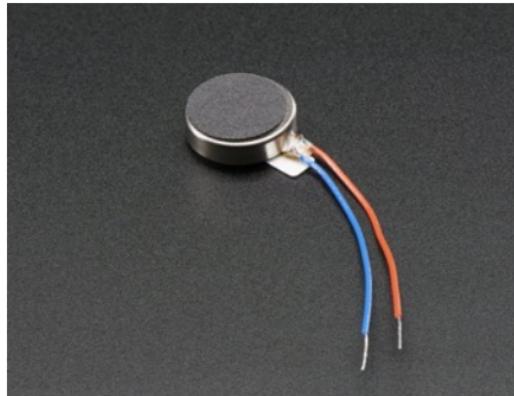
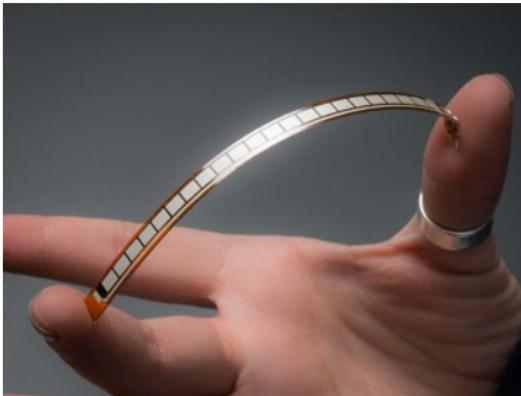
VRduino



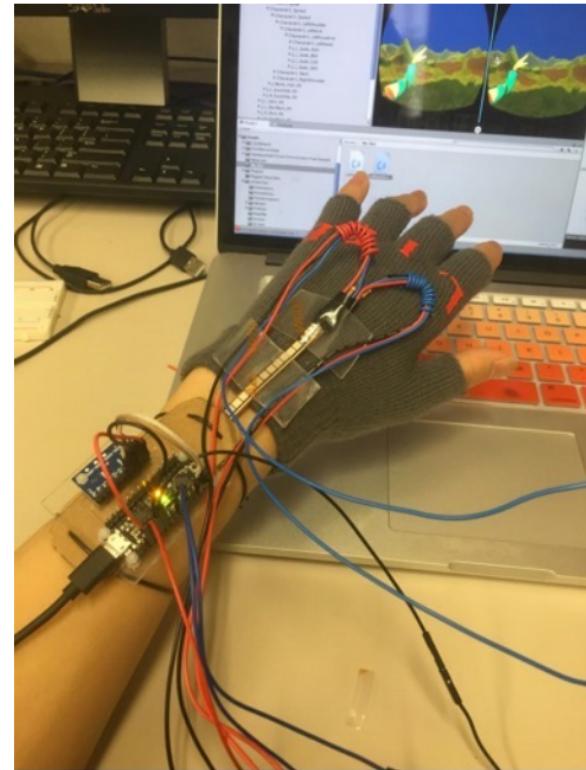
- Teensy 3.2 microcontroller (48 MHz, \$20) for all processing & IO
- InvenSense 9250 IMU (9-DOF, \$6) for orientation tracking
- Triad photodiodes & precondition circuit (\$1) for position tracking with HTC Lighthouse

Some Student Projects - Input Devices

- data gloves with flex sensors
- different types of controllers with tactile feedback via vibration motors
- all connected to VRduino GPIO pins



images from Adafruit.com



About EE 267

- all important info here: <http://stanford.edu/class/ee267/>
- plenty of (zoom) office hours and Ed Discussion: see website
- contact: ee267-spr2122-staff@lists.stanford.edu

About EE 267 - Prerequisites

- strong programming skills required (ideally JavaScript)
do NOT take this course if you have not programmed!
- basic linear algebra required – we will start dreaming
about 4×4 matrices (must know what a matrix, matrix-vector product, etc. is)
- introduction to computer graphics or vision helpful

About EE 267 – Lectures & Labs

- 2 lectures per week: Mo/We 9:45-11:15 am
 - Not sure yet how to support video recordings (**please vote**):
 1. No videos (default options)
 2. Recorded zoom sessions from last year
 3. Flipped classroom
- 1 lab per week starting in week 1 (do at home, will release writeups and videos with links to online tutorials and other important things)
- you will need the skills of the lab to complete the homework, so *do the lab first and then start working on the homework!*

About EE 267 – Labs & Assignments

- labs and homeworks released every Friday
- do all of these at home by yourself or in small teams
- we will hand out all required hardware (details later)

About EE 267 – Office Hours

- Gordon (instructor): Mondays 12:30-1:30 pm, zoom
talk about projects, VR, course logistics, etc.
- Manu (TA): Tue, 2-3pm, zoom
- Suyeon (TA): Thu, 4-5pm, zoom
talk about labs, assignments, ...

All zoom links are on canvas!

EE 267 – 3/4 unit version

Both versions:

- 6 assignments covering all aspects of VR tech: 2x basic computer graphics, 2x perception+graphics+optics, 2x tracking
- Final project (hardware, software, or perceptual experiments) worth ~ 2x regular homework

3 Unit version:

- 1-2 page project report

4 Unit version:

- 6–8 page project report required (more details on website)

EE 267W – 5 unit WIM version

- satisfies writing in the major requirement
- only available for undergraduates already enrolled in the 4 unit version
- will get extra weekly writing and peer-reviewing assignments + 2 writing / presentation workshops
- *talk to instructors if you want to do this in first week of class!*

Requirements and Grading

- 6 assignments (teams of ≤ 2): 60%
- 80 minute (in-person or remote) midterm: 20%
- project (teams of ≤ 3): 20%
 - discuss project ideas with TA & instructor!
 - final presentation (video recordings) due 5/25/2022 at 11:59pm
 - reports & code due (gradescope): 5/27/2022, 11:59pm

Course Project Deliverables

- May 25 (11:59pm): submit your project presentation video
 - Record screenshots / videos of your demo or poster
 - see poster template on website (for non-demoable projects)
- Sorry, no final demo session due to COVID-19 ☹

Course Project Deliverables

- May 27 (11:59pm): report + source code
- report (3 unit course version) = 1-2 page summary with the same topics listed below, just shorter (think “extended conference abstract”)
- report (4/5 unit course version) = conference paper format 6-8 pages with
 - abstract
 - introduction and motivation
 - related work
 - your thing
 - results, qualitative and quantitative evaluation
 - discussion, future work, and conclusion
 - references (scientific papers, not websites)
 - see latex template on website (will be there)

Possible Course Projects

- be experimental!
- for example:
 - Default: build an elaborate virtual environment, e.g. with unity
 - psycho-physical experiments (e.g. test stereo rendering with color/gray, low-res/high-res, ...)
 - hardware projects: IMU, positional tracking, eye tracking, haptics, ...

Relevant Scientific Venues

- ACM SIGGRAPH / SIGGRAPH Asia conferences (general computer graphics)
- IEEE VR, ISMAR, VRST conferences (focused on VR/AR)
- HCI conferences: ACM SIGCHI, UIST, ...
- Optics journals: OSA Optics Express, Optics Letters, Applied Optics, ...

Tentative Schedule

<http://stanford.edu/class/ee267/>

Questions?